Assimilation of GPM and other Satellites' All-sky Microwave Radiances for Hurricane Prediction

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Introduction

Minamide and Zhang (2017, 2018) showed promise in assimilating all-sky infrared (IR) brightness temperatures (BTs) for improved hurricane analysis and prediction through enhancements to the PSU-EnKF system originally developed for assimilating Doppler radar observations. Their work is extended here to assimilation of passive microwave (MW) imaging observations in all sky conditions.

Sieron et al. (2017, 2018) developed cloud scattering properties in the microwave for the Community Radiative Transfer Model (CRTM) based on microphysics scheme particle size distributions and utilizing non-spherical particle scattering properties. In a series of experiments they showed that the Liu (2008, MWR) sector snowflakes were most effective in lowering 183.31 GHz ice precipitation-affected BTs below BTs at 91.7 GHz, in agreement with observations (Figures 1 and 2).

Figure 1. (a) F16 SSMIS observed brightness temperatures (K) at 91.7 GHz (SSMIS channel 18). CRTM-simulated 91.7-GHz brightness temperatures using (b) cloud scattering properties based on microphysics-consistent spheres for all ice species and (c) sector snowflakes in place of the spheres for the snow species.

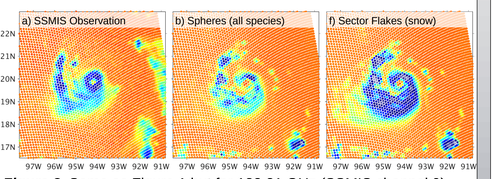


Figure 2. Same as Figure 1 but for 183.31 GHz (SSMIS channel 9).

Application to Harvey

Case: Harvey (2017) while in the Gulf of Mexico

- Ensemble spin-up from 00-12 UTC 23 August
- PSU-EnKF system (WRF model with WSM6 microphysics and 3-km inner domain grid spacing) hourly cycling with 61 members

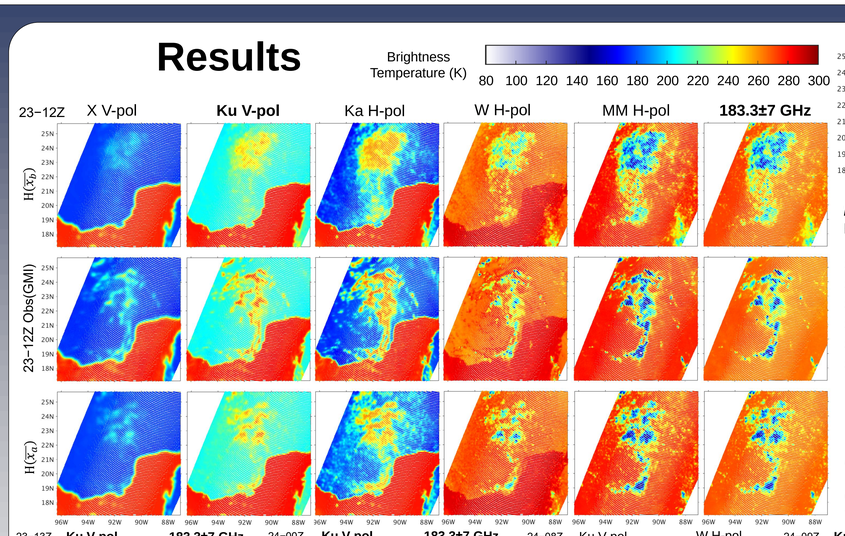
Observations Assimilated

- Microwave (MW) imager BTs only at times when BTs at 19 GHz vertical polarization (V-pol) are available along with either 183.31±6.7 GHz (preferred) or ~90 GHz (H-pol) BTs (high-resolution inner domain CRTM radiances are convolved to imager beam [Sieron et al. 2017])
- Infrared (IR) GOES-16 ABI channel 8 (upper-level water vapor) BTs hourly (Minamide and Zhang 2018, MWR), except in cycles when MW observations were assimilated
- IR/MW BTs assimilated only in the inner-most domain
- Hurricane Position and Intensity (HPI) assimilated hourly and on all domains

Tools

- Successive covariance localization (Zhang et al. 2009, MWR)
  - MW: large 200-km radius of influence (ROI) has no hydrometeor updates, observations filtered to 36 km^2; small 60-km ROI has hydrometeor updates, observations filtered to 24 km^2
  - IR: same as MW but 30-km small ROI, and filtering to 24 km^2 and 12 km^2
- Relaxation to prior perturbations (RTPP; Zhang et al. 2004, MWR): 0.75
- Adaptive Observation Error Inflation (AOEI; Minamide and Zhang 2017)
  - Default observation error for MW and IR BTs: 3 K
  - Inflate an observation's error if the innovation is high and the background error estimate is low
- Adaptive Background Error Inflation (ABEI; Minamide and Zhang, submitted to QJRMS)
  - Multiplicative inflation at locations in which observed clouds are not present in the EnKF background
  - Initially developed for and based on IR assimilation; applied here only in cycles when IR is assimilated

Results



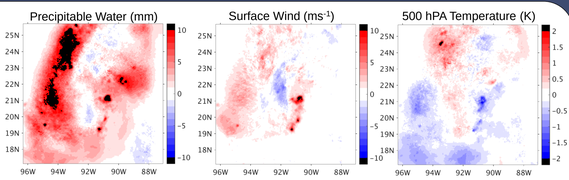


Figure 4 (top). Increments to non-precipitation variables from assimilating GMI Ku (19.35-GHz) V-pol and 183-GHz BTs at 12 UTC 23 August.

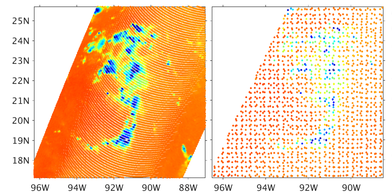


Figure 5. Demonstration of (right) filtering from the (left) GMI full observation for selecting observations to be assimilated at 183 GHz. Diamonds are for 200-km ROI with no hydrometeor increments and circles are for 60-km ROI with hydrometeor increments.

Figure 3 (left). Demonstration of GMI and HPI assimilation for Harvey (2017) at 12 UTC 23 August. CRTM BTs of EnKF (top) background and (bottom) analysis compared against (middle) GMI observed BTs. Of the six frequencies shown, only the Ku (19.35-GHz) V-pol and 183-GHz BTs are assimilated (emboldened labels).

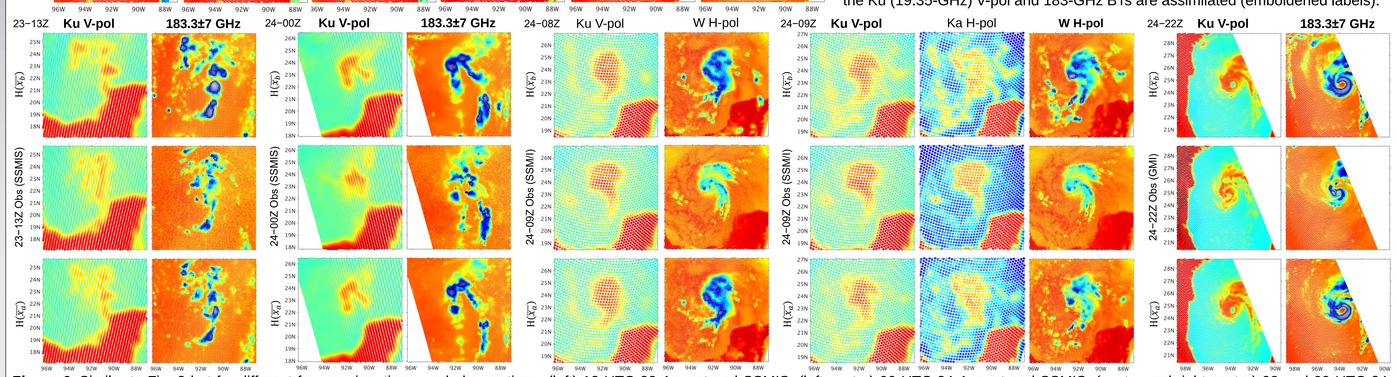
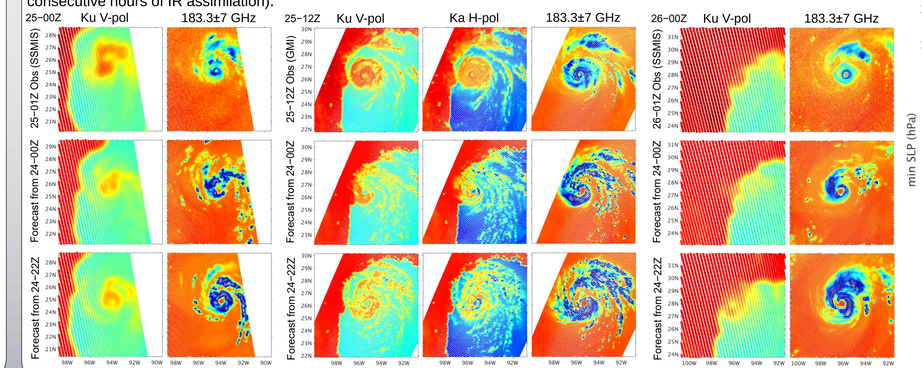


Figure 6. Similar to Fig. 3 but for different frequencies, times and observations: (left) 13 UTC 23 August and SSMIS; (left-center) 00 UTC 24 August and SSMIS; (center and right-center) 08 and 09 UTC 24 August and SSM/I; and (right) 22 UTC 24 August and GMI. All but 08 UTC 24 August have the shown MW observations assimilated; 08 UTC 24 August has IR observations assimilated (and follows 7 consecutive hours of IR assimilation).



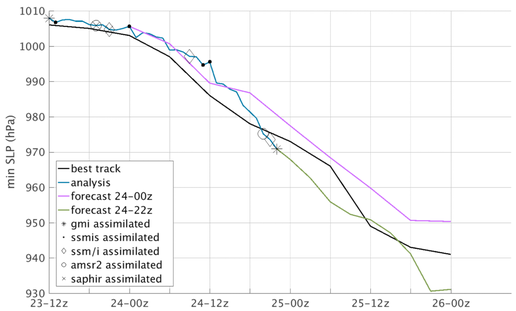


Figure 8 (top). Harvey (2017) central minimum sea-level pressure in EnKF analysis, forecasts, and best track data through time. The times at which microwave observations from the specified sensors are assimilated are indicated by specific icons.

Figure 7. Similar to Fig. 6, but comparing microwave BTs observed and forecasts initiated from EnKF analyses at 00 and 22 UTC 24th.

Points of Discussion

- Unlike free-running forecasts, early EnKF cycle background MW brightness temperatures (BTs) correspond well with observations.
- As cycling progresses, significant negative biases of EnKF background BTs emerge.
  - Intensifying storm and IR assimilation lead to more snow.
  - Graupel concentrations increase as the storm intensifies and the ensemble members converge.
- Generally, assimilation of IR BTs leads to lower MW BTs in the analysis, while 19-GHz and 183-GHz assimilation raises MW BTs.
- Long early morning/afternoon (UTC) gaps between MW imaging overpasses are troublesome.
  - DMSP satellites (SSMIS) now have highly clustered equatorial crossing times
- A center of circulation is not obvious single IR or MW satellite images until SSM/I at 09 UTC 24 August. Analysis from assimilating these MW observations has some of this appearance.
- SSM/I 19-GHz BT observations have large effective fields of view and are notably sparse with insufficient observation density to fulfill the filtering requirements

Conclusions and Future Work

- EnKF assimilation of all-sky microwave and infrared imager observations can produce analyses and subsequent forecasts which correspond well to observed tropical cyclone intensity and precipitation fields
- Optimal AOEI and SOI parameters for microwave BT assimilation have not yet been determined (values used were largely borrowed from IR experiments)
- Develop a microwave brightness temperature definition of cloudy sky for application of ABEI
- Less frequent or more strategic IR BT assimilation might maintain more ensemble spread
- Continued investigation of cloud scattering properties, including non-spherical graupel particles or Liu (2008) dendrites

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